LEAP HI: Engineering Smart Solutions to Enhance Resilience and Sustainability of Built-up Environments under Changing Climate

1. Introduction

1.1. Motivation: The objective of the proposed research, education, and social implementation activities examines the fundamental question of promoting sustainable floodplain, improved water quality, and ecosystem restoration to address engineering issues and their impacts due to changing climate. The proposed study will focus on regions chronically impacted by anthropogenic modifications, climate change and advance knowledge about the socio-economic impact of floodplain management. The underlying goal will be to rehabilitate the effects of climate change and human interventions on the flood control systems, water quality and ecosystem services. The findings of the proposed research will assist engineering managers to implement state of the art knowledge and provide a sustainable approach to regions with similar issues through the partnering effort between scientists, professionals, and stakeholders comprising of civic partners and community residents. The project will be coordinated by a **Professional Project Manager (PM)** Mr. Eric Gruenenfelder, Director of Parks and Recreation who will develop project performance metrics, manage project communications to ensure the development and implementation of an integrated communication system to collect, generate, and disseminate relevant information to project stakeholders and to all interested parties. The proposed research will also involve students and give exposure through outreach activities especially to underrepresented students, such as African American, Native American, Hispanic, Latin and female students. Under the PI's guidance, students will improve their skills for future interdisciplinary research. Additionally, we will design new courses at Southern Illinois University Carbondale (SIUC) and Edwardsville (SIUE) to train and educate students in the Civil and Environmental Engineering Program and Sociology Department.

Transferability: Deer Creek Watershed and East St. Louis in Cahokia Canal/Horseshoe Lake Watershed have a long history of flooding problems resulting in deterioration of water quality and community health particularly related to increased urbanization, poor management of stormwater infrastructure, and coupled by changing climate. The proposed study explores flood and riparian ecosystems within the Cahokia Canal/Horseshoe Lake Watershed and Deer Creek Watershed and its implications on sustainability. Similar flooding, ecosystem, and riparian challenges are common and increasing in communities located along creeks and rivers in the US. Although this study is specifically applied to the East St. Louis area within the selected watershed, similar studies can be developed to better understand urban flooding issues impacting engineering infrastructures and community health in other regions with similar problems. As such, the long-term goal of this research is to investigate the transferability perspective to other communities.

"The consequences of anthropogenic activities and climate change are inevitable; however while improved mitigation can minimize critical impacts on society and the environment while increasing the quality of life."

1.2 Background: Based on the IPCC 2018 report, the direct risks of global climate change are expected to have growing effects in urban areas. Urban growth is accompanied by landscape modification and an increase in impervious areas, thereby increasing urban flooding vulnerability (Meyer et al., 2013, Revi et al., 2014). The core element of urban infrastructure is asphalt and concrete which contribute to the surge of gray infrastructures (Wilbanks and Fernandez, 2014). Urban development thus often results in increased surface runoff due to deteriorated pervious surfaces. Moreover, the risks of urban flooding are exacerbated due to destructive runoff flow velocity along with extreme peak flows (Li and Wang, 2009). Some of the flooding events over the past 25 years in the central U.S. severely disrupted societal functions and led to fatalities and large financial losses (Xiao et al. 2013). In the past three decades, flooding has resulted in losses of ***$8.2bn*** each year on average according to the National Weather Service, Flood Loss Data of 2015. The implications of urban flooding are not limited to just human and economic losses. It poses a greater health related threat as sewer overflow and entry of contaminated water can lead to outbreaks of diseases (Chen et al., 2015). Furthermore, the projected increase in the magnitude and frequency of precipitation events attributed to climate change pose significant effects on rivers and their riparian zones (Garssen et al., 2015). Anthropogenic activities affect the overall climatic balance leading to changes in precipitation patterns. Therefore, it is of paramount significance that restoration activities be carried out by state and local administrations considering the projected impacts of climate change.

Flooding is the most costly and common natural disturbance affecting the United States. Every 9 out of 10 presidential disaster declarations are flood related. Misguided efforts in the early- to mid-20th Century concentrated on mitigating flood losses through building various flood control infrastructure that modified river morphology and degraded riverine habitat over time. This had led to people and assets becoming increasingly vulnerable to flood-related disasters (UNISDR, 2013). Increasing losses are expected in many inter-dependent domains such as health, security, and economic and societal well-being. Pervasive flooding, as exemplified in the project area, is rooted in a changing climate, urbanization, and improper flood-control infrastructure. These mechanisms can be focused on bettering the functioning of floodplain ecosystems in a basin. Floodplains are the integral intermediate habitat between river and terrestrial ecosystems (Mitsch et al. 2008). A well-functioning floodplain enables a healthy water balance, provides sediment control and promotes sustainability, thus benefiting society and the environment.

Natural floodplains are largely undeveloped areas that primarily serve as habitats to indigenous species. However, natural floodplains can also drain excessive amounts of storm water during floods, thus preventing serious harm to humans. Conversely, anthropogenic activities pose severe stress on natural floodplains resulting in an imbalance and transformation of the natural functioning of the floodplains. Anthropogenic activities often change the storage and conveyance of water, nutrients, and sediments affecting the ecosystem and community health. To overcome this, water and ecosystem managers are prompted to restore a channel configuration to promote the natural functioning of the rivers. Primarily, ecosystem restoration is intended to improve the natural recharge and storage of a river reach by increasing the detention and retention time, which will reduce the flood peak downstream. *In an urban setting, upsizing the pipes is not a good alternative, so sustainable and resilient options in terms of Green Infrastructures (GI) and multiuse detention facilities are effective to reduce flooding. They help in improving water quality in urban areas where open spaces are limited and have high pollution.* This, in conjunction with flood plain mapping, forecasting, and enhanced ecosystem services, provides a strong long-term mitigation option. Machine learning (ML) is one of the components of Artificial Intelligence (AI) who's algorithmic and heuristic approach help to understand patterns in certain dataset through intuitive training applications for flood prediction. ML approaches have very powerful implements to different characteristics such as stage-discharge relations, rainfall-runoff calculation, flood mapping and flood prediction of water resources engineering.

Homelessness is one of the most significant issues affecting human health, well-being, and ecosystem services in the United States. On any night, more than 500,000 people experience homelessness in the U.S., and that number is now rising after several years of decline. In fact, the number of unsheltered homeless individuals increased by 9% between 2016 and 2017. The problem is particularly evident in East St. Louis, which has the 5th largest increase in the homeless population in the country in 2016-2017 being in a city of roughly 25000 people. The racial disparity in experiencing homelessness is evident in East St. Louis (Figure 1). The percentage of homeless and unsheltered that are Black in East St. Louis is 76%, which represents the highest unsheltered rate in the nation. Even more concerning is the fact that East St. Louis was the 4th largest city in Illinois in 1950, but since then has continuously declined and now has less than one-third of the people it had in 1950. It also has

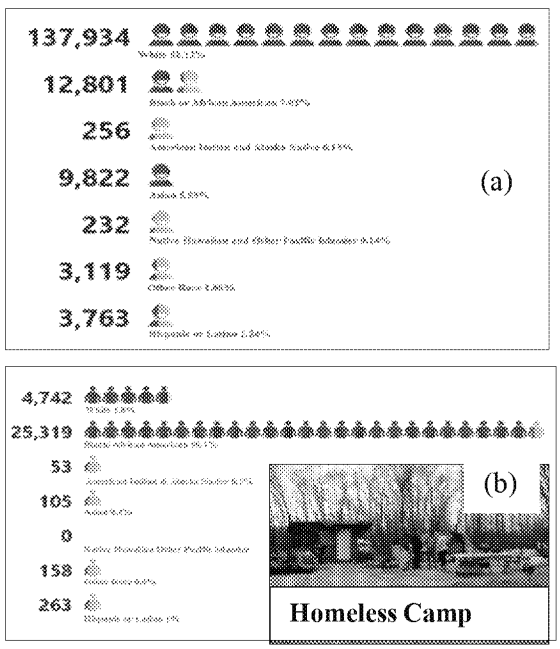

Fig 1. Racial and Ethnic Composition of (a) Deer Creek Watershed (b)East St. Louis and photo of a Local Homeless Camp

the highest proportion of African Americans, with 98% of the population identifying as Black or African American.

Beyond the socioeconomic plight, there are also environmental consequences associated with the unsheltered homeless due to improper waste disposal, poor sanitation practices, and inadequate facilities (Figure 1). Considering that the time between measurable rainfall events is sometimes as long as three months, the fecal contamination could potentially accumulate and lead to a tremendous pathogen spike to the drinking water infrastructure during storm events. With this increased risk of waterborne disease, there is also potential for the wastewater infrastructure to be inappropriately implicated, thereby threatening the moral and cognitive legitimacy of potable reuse (Harris-Lovett et al. 2015). Moving forward, it is important to not only address specific symptoms (e.g., water pollution, waterborne disease) but also major human (e.g., poverty) and ecosystem (e.g., water scarcity) stressors and modifying factors (e.g., long-term drought) exacerbating the issue of homelessness. An improved characterization of the homeless population and its potential impacts on public and environmental health is only the first step to enacting change. Despite the ongoing economic recovery, homelessness is a serious problem that will continue to plague communities throughout the U.S. Therefore, policymakers and other stakeholders must become more familiar with the dynamics of homelessness and its potential coupling with critical resilient interdependent infrastructure systems and processes. The proposed research employs a transdisciplinary approach to characterize the interdependence and resilience of (1) flood control systems, (2) water quality sampling and monitoring, (3) in-stream restoration efforts, (4) usage of deep leaning method's for improving water quality and aquatic habitat, and (5) climate-resilient water infrastructure systems in an urban setting.

1.3 Project Goals and Objective: The project will focus on integrative research that addresses fundamental technological and social science dimensions to evaluate engineering solutions together with communities. The project will promote a sustainable approach to maximize flood resilience and ecosystem restoration within the study area using state-of-the-art technologies by providing an ample platform for communal involvement. The research will incorporate the multidisciplinary perspectives of scientific areas jointly addressing the technological and social science dimensions of communities. The key goal of this research proposal is based on fulfilling the technological and social science dimensions that are highly relevant to advance the watershed management goals (stream bank restoration, resilient green infrastructure, water quality monitoring, and resilience to flooding), maintain the ecological processes and support stakeholders. The technological-cum-social aspect based goals of this work are: (1) Evaluate the impacts on water quantity/quality as a result of climate variability and anthropogenic modifications of the floodplain; (2) Assess the floodplain management system based on implications to future climate change and community; (3) Restore the riparian (Deer Creek) and aquatic (Cahokia Canal/Horseshoe Lake) ecosystem in an urban setting; (4) Analyze the ways to develop the flood-prone area into a community-friendly space (5) Generate a framework for sustainable floodplain management; (6) Assess the source of water pollutions via field observation and laboratory analysis and simulate water quality responses to the floodplain restoration and pollution control scenarios via modeling; and (7) Based on the created framework, communicate the new knowledge to stakeholders (agencies and users like city residents) for data accumulation and decision-making processes.

1.4 Research Questions: The study will contribute to the body of knowledge for water and ecosystem management integrated with communities by asking (1) How resilient is each community and ecosystem within the existing floodplain; and what are the prospects of increasing community resilience within the chronically impacted areas?(2) What will be the future flood scenarios under changing climate and urbanization?(3) What improvements are needed to improve community resilience and to restore the ecosystem and water quality?(4)How will floodplain restoration help in improving ecosystem processes?

1.5 Outcome of the Project: The significance of the research is installation of rainscaping features know as Best Management Practices (BMPs) including rain gardens, permeable pavements, lawn alternatives, vegetative buffers as stormwater management efforts for beautification to engineered systems of GI networks (Figure 2), which are designed to mimic the hydrology of natural landscapes that enhance water infrastructures resilience. This project employs a systematic approach that could be practicable to implement in local conditions. Test case studies will be conducted in the selected watersheds where engineering issue related to urban flooding is prevalent but both regions have differences in racial disparity. This will help improve the ongoing stormwater and water quality issues and establish the basis for replication in a wide range of communities. In-stream restoration efforts to revitalize the creeks will help in improving the water quality and aquatic habitat and in turn improves the health and prosperity within the community. For both the study area, we propose an integrated watershed hydrological, high-resolution 2D hydraulic and riparian and aquatic habitat modeling to study flood mitigation and riparian aquatic. The hydraulic model will include the quantification of inundation extent during different flood events, including the 100-year recurrence interval. Hydraulic modeling of urban streams and the floodplain will be used to delineate high-risk areas for flooding and estimate the flood inundation extent. The model can be used to assess habitat conditions (e.g., riparian) for different flow scenarios. The riparian vegetation model will be used to update and improve current vegetation plans if modeling results indicate different recruitment strategies will have higher survival rates. Moreover, the proposed project will be aligned with the mitigation/restoration implementation plan. The project will be guided by the following hypothesis:

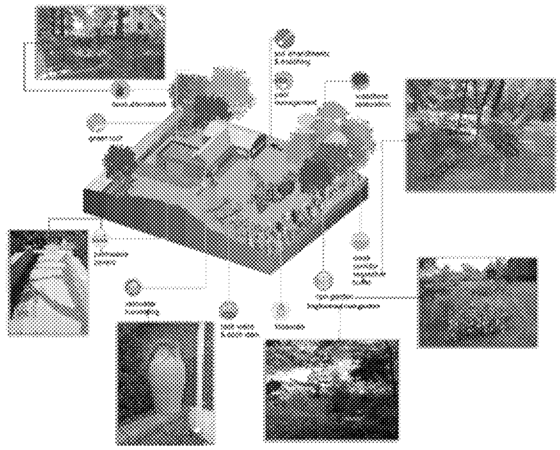

Fig 2. Rainscaping-Beautification to Engineered System

1. ***Water Resource Engineering:*** Stormwater infrastructures will help to manage urban flooding issues. Changing climate coupled with increased urbanization results in system failures. The current project will analyze, evaluate, design, install, and monitor resilient stormwater management infrastructures to improve urban sustainability under changing climate. BMPs and in-stream restoration features will enhance sustainability of water systems.

2. ***Environmental Engineering:*** Flood control and wastewater infrastructure, urban runoff and coal mining site contribute pathogen and heavy metal loadings that may lead to adverse public health impacts in downstream systems, and these impacts will be quantified using the models.

3. ***Ecosystem:*** Ecosystem services connects human impacts (change in land use), flood hazards, and social benefits. The hydrological model quantifies to develop matrices of how watershed management impacts runoff in urban streams and helps to design flood mitigation approaches.

4. ***Computer Science:*** The ML is an advanced method to improve the quantification related to water and aquatic habitat quality. ML improves the traditional methods used for sustainable water systems.

5. ***Social Science:*** Given the demographic and socioeconomic differences between the communities located in the two study areas, one middle-class and racially diverse and the other largely African American and poor, residents from the two communities will have differing needs with respect to flood control, wastewater infrastructure, and greenway development.

2 Project Description

2.1 Intellectual Merit: The research components of this interdisciplinary approach will focus on analyzing the flooding, water quality and ecosystem issues that are interlinked with the climate and impacts due to human interventions in the form of urbanization. Understanding the impacts of floodplain improvements on society will increase the resources of similar works in the future. Intellectually, we attempt to explain (i) how developed flood zones impact residents (ii) how residents perceive flood zone restoration and identify any barriers to ecological restoration, (iii) how flood zone restoration impacts a community's natural and social capitals, and (iv) how quality of the surface waters benefits from the floodplain restorations. To. To answer these questions, a team of engineers, city officials, social and environmental scientists will (i) survey nearby residents to find out how urban flooding affects them and how they would like to see the flood zone transformed (ii) hold focus groups to learn about any local challenges residents may have including trust in local government, access to outdoor recreation and natural landscapes, and opportunities to meet people and socialize, (iii) survey residents after the flood restoration project is complete to monitor its effects on local residents, and (iv) conduct field sampling and laboratory analysis, prior and after implementing the restoration plans, and tune water quality model to the region to predict responses to various future scenarios.. Thus, this project will study ecosystem restoration techniques to mitigate flooding, create a natural landscape for recreational uses, increase community connectivity, and seek to increase social capital and community sentiment among residents. The project will deal with the multidisciplinary approach to various complex problems and engage different entities such as community members, researchers, professionals and stakeholders. This study will also explore the technical knowledge and computing advances along with its societal benefits for developing the internet-based flood alert system. Many natural-restoration focused engineering studies rely heavily on modeling alone, but this project is valuable because it is rooted in an accessible field site with full cooperation of the municipal owner. A balance of field data and numerical modeling will enable better calibration and validation of future modeling and design efforts. In turn, this will make the case for ecological restoration for flood mitigation more convincing and its implementation more likely to be shared. This study will provide crucial information about the inter-relationship between riverine physical, chemical, biological and ecosystem processes. Furthermore, it will quantify the benefits of restored flow and water quality on riverine ecosystems as well as societal benefits.

2.1.1 Flooding Issues: Both Deer Creek watershed in Missouri and the City of East St. Louis located within Cahokia Canal/ Horseshoe Lake in Illinois experiences chronic flooding. Several flooding events over the past century in the historically vulnerable area indicate a need for a sustainable approach to mitigate future flooding. Deer Creek watershed has experienced 26 damaging flooding events since 1957. In September 2008, a flash flood on interior streams, had a significant impact in St Louis County damaging 302 commercial properties. The frequent inundation of properties and the roadway itself has been a concerning problem for city officials and residents, often raising questions regarding public safety and property damages. Additionally, the degraded floodplain has decreased the availability of natural greenspace to residents. Due to public health and safety concerns, some parts of the area surrounding the creek have been declared as **'blighted'**. Recurrent flooding has led the area to be less desirable, resulting in real estate and sales tax decline. Building and site improvements have become depressed, businesses have moved out, and properties have remained on the market for extended periods. ***Without the flood mitigation efforts, this decline is expected to continue.*** The adverse effect of the flooding problem around the creek directly impacts many of the businesses along Brentwood City, who are forced to sandbag and evacuate during heavy rainfall events. Boat rescues have been necessary during dangerous events, including the record events in 2008. ***Severe flooding escalates quickly and unexpectedly often reaching to three feet of water in the first 10 hours of a heavy rain event. Business owners along Manchester Road at times are left with no other option than to flee their businesses in order to protect their lives.*** Continuous flooding has led to stagnant economic growth of the area. In addition, flooding has turned the creek area into a neglected space with limited public recreation potential and has threatened the limited aquatic habitat. Since 1981, local and federal entities have repeatedly investigated the scope of the flooding problem, ecosystem degradation, and mitigation options. In 1988, the St. Louis Metropolitan Sewer District (MSD) generated updated hydrology for Deer Creek through their Storm Water System Master Improvement Plan. The professionals developed four projects for the consideration of the City and its Board of Aldermen, who ultimately approved an alternative in 2017 as the preferred plan to address the flooding problem along Deer Creek. The approved alternative, is implementing the stream bank stabilization and restoration. The mitigation features are expected to reduce construction and maintenance costs while still achieving the restoration of Deer Creek and Harding Ditch in East St. Louis into a viable ecological habitat that safely conveys the 100-year flood. Thus, ***both communities will promote flood resilience by transforming a previously developed urban space prone to flooding to a restored recreational green space.*** These efforts will improve community resiliency in a changing climate. The incorporation of real time flood alert technology will also improve resiliency by alerting stakeholders to prepare for potentially destructive events

2.1.2 Water Quality and Public Health: The Deer Creek Watershed is a sub-watershed to the River Des Peres Watershed. Sections of Black Creek, River des Peres and Deer Creek are listed on the Missouri Section 303 (D) list of impaired waters for E. coli, chlorides, and Clean Water Act for low Dissolved Oxygen (DO). The watershed is along the receiving end of water from **37 square miles** of the fully developed urban watershed from **22 different towns**. A study conducted by Washington University in St. Louis revealed that some of the unhealthiest water quality parameters in the Deer Creek watershed are in or near the proposed project area. The lowest average DO level of the sample sites was located approximately 0.7 miles downstream from the Deer Creek project area. Floodplain restoration will not only decrease flood levels but will mitigate poor water quality.

In Cahokia Canal/Horseshoe Lake Watershed Prairie du Pont Creek and Harding Ditch impairments listed in 2018 include DO, and past impairment include total phosphorus, total suspended sediment and fecal coliform, all of which can contribute to harmful algal blooms. Schoenberger Creek's impairments include bottom deposits, Total Phosphorus, sludge, turbidity, Ammonia, Manganese, and low DO, all of which contribute to human and ecological health problems. Frank Holten Lake's main impairment is Polychlorinated Biphenyls (PCBs), highly toxic chemicals that can affect the liver, cause birth defects, and effect development health in young children. In addition, in 2009 the Illinois state ***EPA declared that the Harding Ditch, which drains the American Bottom, contained hazardous levels of fecal coliform.*** It has become, effectively, an open sewer. The most recent Centreville flood occurred on January 11, 2020. The degraded creek adds to the growing concerns over the safety of the residents and its impact on public health.

Chemicals classified as Contaminants of Emerging Concern (CECs) have been found in most urban environments and they are linked with several endocrine, reproductive, neurologic, and carcinogenic effects in biological systems. CECs broadly include pharmaceuticals, personal care products, pesticides, industrial additives, and other unregulated anthropogenic chemicals (Mnif et al. 2011, Rahman et al. 2009). The runoff from agriculture and livestock areas, leakage from landfills and sewage treatment facilities, industrial waste systems, septic tanks and effluents from municipal wastewater treatment plants are the main sources of CECs (Mompelat et al. 2009). Despite numerous investigations, substantial gaps remain in our knowledge of CECs fate and transport.

***2.1.3 Ecosystem Services*:** There is an important but complex (two-way) relationship between habitat status, species biodiversity and ecosystem processes (Doherty et al. 2000; Maes et al. 2018; Naiman et al. 2005; Burkhard et al. 2012). Human-induced impairment of urban runoff leads to deterioration of recreational and drinking water quality and reductions in human well-being and ecosystem services. Yard waste decaying in creeks and rivers decomposes in a process that removes oxygen from the water. Fish and other aquatic life can't survive in water with low oxygen. As yard waste decomposes, plant nutrients such as nitrogen and phosphorus are also released. These nutrients promote the excessive growth of algae in the water. As the water becomes polluted, it does not support aquatic life deteriorates water quality and becomes a health hazard. Leaves and woody debris naturally accumulate in streams and creeks, however, when you collect and dispose of yard waste along creek banks, the added yard waste covers the ground and keeps out the natural vegetation that helps to stabilize the bank. This practice leads to increased erosion and sedimentation that clouds creek water and destroys habitat for aquatic life (Figure 3). Improper disposal of yard waste increases the accumulation of debris which in turn can lead to blockages that inhibit proper drainage.

Fig 3. Erosion is evident along Deer Creek near Litzsinger Road in Ladue.

2.2 Technical Approach:

2.2.1 Hydrologic and hydraulic modeling for the study area

Development of hydrologic model: A current hydrologic analysis will be carried out using the 'Runoff' module of XPSWMM version 2019, SP1. The modeling work will utilize the hydrologic inputs and parameters developed for the MSD Deer Creek Watershed Storm Water System Master Improvement Plan (1998) (SSMIP) as well as in East St. Louis. This model will be run to develop flows specifically for this study, using design storms that reflect the most up-to-date published and peer-reviewed rainfall intensity-frequency atlas values available. Overland flow will be generated for each hydrologic unit in the watershed using the XP-SWMM RUNOFF block based on properties of the ground slope, width, Manning's overland roughness coefficient, and initial abstractions. The hydrologic model will be delineated into sub-basins within the 37 square mile Deer Creek Watershed and Cahokia Canal/Horseshoe Lake Watershed. Peak flows will be routed through the open channel stream network in SWMM and the open channel system using the 'Hydraulic' module. Flow hydrographs for the project will be extracted from the XPSWMM model at the design points from both the Runoff and Hydraulic module. The number of critical points for BMPs installation and several other flood control infrastructures including detention and retention basins will also be assessed in the modelling efforts. The potential locations that will reduce the runoff and improve the water quality will be determined as a preliminary assessment to reduce the flood risk.

Development of hydraulic model: A hydraulic analysis will be conducted to evaluate the proposed project improvements along the stream to help reduce flooding. The U.S. Army Corps of Engineers (USACE, 2016) HEC-RAS version 5.0.3 will be used to perform hydraulic calculations. To estimate the peak stages along the channel, downstream boundary conditions of normal depth will be established, and the unsteady flow simulations will be performed using the relevant flow hydrographs. The hydraulic model will include the Deer Creek channel starting at the mouth of River Des Peres at the downstream end to 3.53 miles upstream, 1.06 miles of Black Creek starting from its confluence with Deer Creek, 0.38 miles of Hampton Branch will also be included from its confluence with Black Creek because of its proximity to the proposed improvements. For the HEC-RAS model, Deer Creek will be divided into two reaches at its confluence with Black Creek. Additionally, Black Creek will be divided into two reaches at its confluence with Hampton Branch. Similarly, the channel along the Schoenberger and Harding Ditch will also be modelled because of its flood impact to Centerville and East St Louis. A networked model that includes junction nodes at the confluences of the creeks will be created because of the need for unsteady flow simulation.

Hydrologic and hydraulic evaluation under changing climate: The main objective of this task will be to evaluate the impact of changing precipitation patterns as evident through climate models within the study region. The proposed floodplain will be evaluated considering the climate change by coupling the climate data with the hydrologic model of the both river system. First, the 6-hour 100-year storm depths will be calculated with the climate model driven datasets of North American Regional Climate Change Assessment Program (NARCCAP). NARCCAP model data sets are available for the time period of 1970-2000 for historic precipitation and 2040-2070 for future precipitation. These data are gridded climate model data of 50 km spatial resolution. The L-moment based Generalized Extreme Value method will be used with the regionalization for the calculation of 6-hour 100-year depth. The 32km resolution of NARR, is more refined than NARCCAP data resolution. NARR data are available from 1979 to 2015, but same 3-hourly temporal resolution. Since the NARCCAP data do not have historic datasets after 2000, this work only considers NARR data from 1979-2000. NARR data will be used for the screening and NARCCAP for the historic design depths. Delta change factor, an alternative of complex downscaling for gridded data will be used for the calculation of climate change derived future design depths. Plugging the calculated design depths into the hydrological model of the watersheds will be used to evaluate the future runoff through the both watershed. Further, the flow quantity obtained from the hydrologic model and calibrated HEC-RAS 2D model will be used to develop a future floodplain map based on climate change. This assessment will result in making the design and management and more resilient to climate change spurred floods.

2.2.2 Water quality assessment

Sampling, laboratory experiment and water quality modeling: This task will investigate the water quality of the study watersheds to identify the major sources of pollution to examine the current level of water impairment against the drinking and recreational water quality standards and to address various pollution control strategies. **Sampling Locations:** The water quality sampling will be conducted in five reference points along the Black Creek and Deer Creek and three discharge points from Hampton Creek and runoffs from surrounding agricultural land and municipal effluents (Figure 4). Concurrently, water quality will be monitored at six reference points along the Schoenberger Creek and Harding Ditch and four affected stream reaches in which discharges from Grand Marais Lake, urban runoffs and tributary washes along the homeless corridor present (Figure 5). Sampling locations will be re-evaluated after assessing the results of the initial sampling event, with the potential for adding additional locations. Flow rates will be tracked at sampling locations to facilitate mass loading calculations. **Target Constituents:** All sampling locations will be monitored for various water impairments that contribute to human and ecological health problems including CECs, DBPs, fecal coliform, total mercury, methylmercury, and selenium. In consort with these water impairments, typical water quality parameters such as biochemical oxygen demand, DO, total organic carbon, chloride, total nitrogen, ammonia, nitrate, phosphate, pH, total suspended solids, turbidity, and temperature will be measured to quantify water quality index. ***CECs:*** We will apply a suspect screening method for a broad suite of CECs. To facilitate suspect screening, we will curate a database containing compound-specific information of over 2,000 CECs from multiple public databases. We will use a mass balance approach to assess loads, sources, and transport of the most frequently detected CECs in two urban watersheds under different seasonal and hydrologic conditions. ***Fecal Coliform:*** We will identify the major source of microbiological pollution by examine fecal coliform at the sampling locations. ***DBPs.*** We will analyze two most common classes of DBPs, haloacetic acids (HAAs) and trihalomethanes (THMs) to fill the gaps in our understanding of these contaminants in the study watersheds. ***Mercury.*** Coal is rich both in energy and contaminants, and coal mining and combustion release these contaminants into the environment. Two contaminants of particular concern in coal pollution are mercury and selenium (Kostova 2017, Coleman et al. 1993). We will study mercury and selenium concentrations in the coal mining impacted aquatic ecosystem in the East St. Louis basin. We will assess the level of these environmental toxicants and examine whether elevated selenium concentrations are associated with decreased organic mercury (methylmercury) concentrations and subsequent bioaccumulation. **Modeling.** We will use a water quality model to simulate the fate and transport of the contaminants and predict future condition under various loading scenarios or management actions. Water quality modeling will be conducted, using QUAL2K model (Chapra et al. 2008). The model will be calibrated to the collected data in year 1, 2 and 3, and then will be validated, using data collected in years 4 and 5 and implement to predict water quality under the scenarios that developed in Hydraulic modeling task. The speciation of mercury will be simulated using Visual MINTEQ. **Developing Total Maximum Daily Load (TMDL):** Following the tuning of the model to the study regions, we will implement it as a predictive device to develop total maximum daily loads for the concern impairments. The TMDL process utilizes the model to project water quality as a function of pollutant loads and proposes best management practices (BMPs). To develop TMDL, we will run the water quality model under a critical low-flow condition. Using the hydrological information obtained from hydrologic and hydraulic compartment of this study, we will be able to determine the standard design flow, 7Q10. The minimum 7-d flow that would be expected to occur every 10 year is generally accepted as the standard design flow. Finally, the model can be applied to determine cost-effective BMP approaches to achieve water quality that fully support the impaired streams.

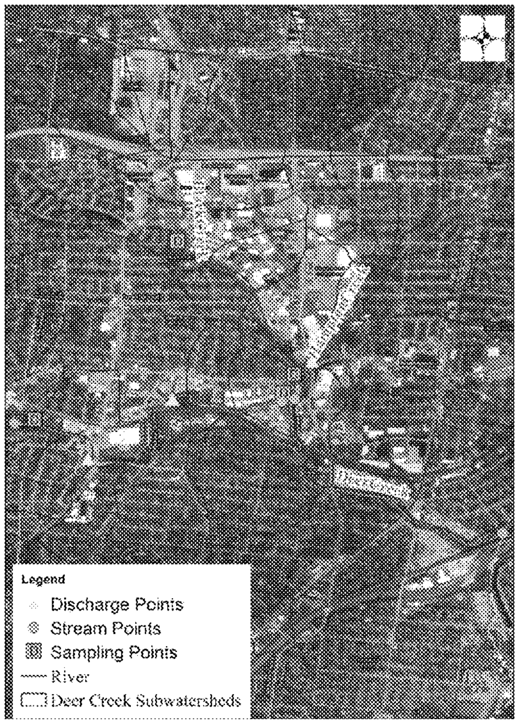

Fig 4. Sampling sites in Deer Creek

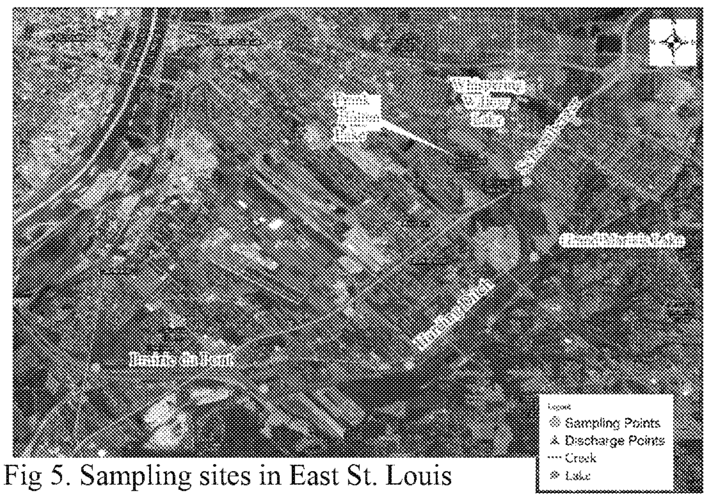

Fig 5. Sampling sites in East St. Louis

Deep learning models for predicting water quality parameters: In this task, we propose to design novel deep learning methods for predicting water quality index (WQI) based on various water quality parameters that measured in water quality section of this study. The proposed methods are flexible, do not require a lot of data, are fast, and can capture non-linear, complex relationships between the input and output parameters. In this regard, we propose a trainable ML method 1) to analyze, evaluate, and assess the dependencies among the input parameters to predict the WQI and 2) to estimate the WQI in case of missing data and input parameters. Our proposed approach is based on recent advances in recurrent neural networks (and dilated convolutional neural networks (Rekabdar et al., 2018) to capture complex time-sequences of various input parameters. In the training phase, the training data are the following input parameters pH, TSS, NH_3, CL, PO_4, NO_3, temperature, turbidity, and E-Coli. In the testing phase, the output is the estimation of WQI. Unlike the other well-known ML approaches such as traditional neural network, support vector machine, Naïve Bayes (Rish et al., 2001), in deep learning methods, less pre-processing of the input data is required. This is an advantage over traditional ML methods. Our architecture learns the high-level features from the input feeds automatically. The high-level representations from the proposed architecture are concatenated, flattened, and used as input to the softmax layer for anticipation. Softmax is the right choice because the classes are mutually exclusive, and the number of choices is not large. The networks in our architecture will be trained and tested using Tensorflow on machines equipped with a Nvidia Geforce graphic card.

2.2.3 Ecosystem Restoration

Development of a 2D Hydraulic model: The HEC-RAS model developed in Section 2.2.1 will be upgraded to a 2D hydraulic model. 2D models can simulate water surface elevation in channels, and calculate water depths, velocities and inundation patterns for rivers and floodplains and can effectively model features like narrow bridges and discrete features. A set of three related models will be developed, which represent current condition (Scenario 1), after floodplain and channel restoration (Scenario 2) and implementing climate change scenarios (Scenario 3). Publicly available existing channel and floodplain elevation data for St. Louis County, MO based on LiDAR survey for Missouri (http://msdis.missouri.edu/data/lidar/) and St Clair and Madison County, IL (https://clearinghouse.isgs.illinois.edu/data/elevation) will be used to develop river bathymetry for the current condition model. For scenario 2 (after floodplain and channel restoration) and 3 (implementing climate change scenarios), modification will be carried out in existing DEM at the areas where channel and floodplains were modified. Daily discharges measured at USGS 07010082 Black Creek near Brentwood, MO and USGS 07010075 Deer Creek at Ladue, MO and East St Louis in IL to perform frequency analysis and estimate different recurrent interval (RI) floods e.g.100 and 500yr will be made. Survey of flow velocity and water surface elevation (WSE) for different flow conditions in the study area will be carried out. Further, Acoustic Doppler Velocity meter (ADV) for velocity measurement at multiple points and water surface elevation for different discharges for calibration and validation of the hydraulic model will be used while WSE will be surveyed using total station or Differential GPS (DGPS). The output will be calibrated and validated 2D hydraulic model for all three scenarios. Furthermore, outputs will be flood inundation extent, water depth, velocity, and shear stress for different RI floods (e.g., 100 and 500-year), future flood inundation extent implementing different climate change scenarios.

Evaluation of riparian vegetation: Based on floodplain physical variables including seed dispersal period, shear stress, mortality coefficient (a function of water surface recession rate), and elevation of topography reference to the mean water level in the channel, riparian vegetation model predicts fully favorable, partially favorable, low favorable and not favorable areas for successful riparian vegetation recruitment, using rule-based Fuzzy approach. Equal weights will be assigned to each parameter and classified into good (G), fair (F) and poor (P) based on to threshold values. We will develop three set of vegetation models, which represent the current conditions (Scenario 1), after floodplain and channel restoration (Scenario 2) and implementing climate change (Scenario 3). An existing riparian vegetation model will be utilized to predict riparian habitat development as a result of current hydrologic conditions, proposed channel and floodplain restoration, and implementing different climate change scenarios (Benjankar et al. 2020).

Evaluation of aquatic habitat: In-stream flow incremental methodology (IFIM) is a most common approach to assess aquatic habitat quality (Bovee et al. 1998), which evaluates habitat quality based on values of physical properties, such as water depth, flow velocity and water quality (e.g., DO, water temperature and nutrients) defined by the biological requirements for different species and life stages. Flow properties are generally simulated with 2D numerical models for habitat analysis. A fish habitat model will be developed in ArcGIS to quantify habitat quality using simulated water depth, velocity, and DO (based on watershed hydrological model) variables. The model quantifies spatially distributed *suitability index (SI)*, an indicator of habitat quality. For the aquatic habitat model, we will use publicly available habitat preference information for hydraulics and water quality variables for the species of interest.

Estimate aquatic habitat quality using Machine Learning: In this task, we propose to utilize novel ML techniques to estimate the aquatic habitat quality. The proposed methods are flexible, do not require a lot of data, are fast, capable of working in real-time, easy to use, and capture non-linear dependencies between the input and output variables. To do this, we propose to design a deep learning method based on deep feed-forward neural network (Hossain et al., 2015) & long short-term memory (HuanG et al., 2015) architecture. The primary components of the proposed model are (1) recurrent layers, (2) convolutional tower, (3) pooling layer, and (4) one fully connected layer for final estimation/prediction. In the training phase, the input training variables are water depth, flow velocity, and water quality (e.g., DO, water temperature, and nutrients). In the testing phase, the output is the estimation of the SI. Our architecture networks will be trained and tested using Tensorflow on machines equipped with Nvidia Geforce graphic card.

2.2.4 Installation of sustainable infrastructure to alleviate flooding and improving water quality: As a part of the watershed management plan initiative, the research work will also drive its focus on installing, maintaining, and monitoring of relevant sustainable infrastructures within the study area based on the findings of the proposed research. A planned landscape improvement for the flood mitigation project will be proposed after the completion of initial floodplain modeling. Improvements will include installation & monitoring of rainscaping (as sample plan shown in Figure 6), BMPs at least 5-years period, stormwater harvesting, stream bank restoration, modification of channel locations using buffer plantings at locations where construction debris and accumulated trash are present. The flood bench will be well-rehabilitated using turf seeding along with storm sewer outfall removal or stabilization. All improvements, when built in conjunction with each other, will serve to mitigate flooding in the project area by providing areas for storage of floodwaters in the restored floodplain bench areas and within the overflow storage ponds and will be resilient to changes in climate patterns.

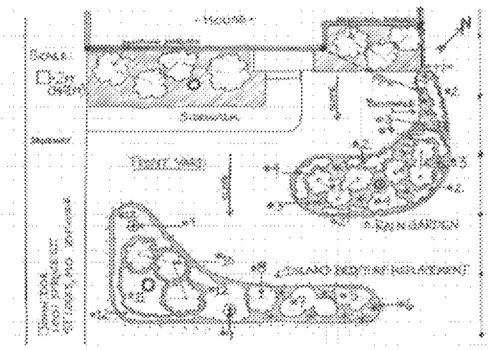
Fig 6. Sample Plan of Rainscaping Features

2.2.5 GIS Framework Development: This task will be focused to develop a GIS-framework for modeling and mapping of flooding, water quality, and ecosystem model outputs in two urban watersheds for present and future analysis. The flood modelling structure will be distributed into four modules (i) delineate watershed; (ii) runoff estimation; (iii) flood inundation extent and mapping; and (iv)calibration and validation. Watershed will be delineated by constructing stream networks and drained into inlet or a low elevation point. Consequently, the flood inundation will be mapped for a given precipitation event. In this framework, runoff hydrograph at the pour point will be generated. In the case of a channel inlet, the runoff hydrograph will be linked with the discharge hydrograph and flooding characteristics will be determined. The flood depth throughout the modelled watershed will be mapped as a flood extent map. Finally, the calibration and validation of a flood model will be performed by comparing the model output with observed data. The flood depth, extent, and velocity for present and future scenarios will be extracted in GIS shape files (vector) or raster dataset. Similarly, riparian vegetation maps, flood plain restoration maps before and after implementing climate change scenarios will also be stored in a database. All the hydrologic, hydraulic, ecosystem, and water quality model outputs as well as all the trained deep learning and ML models will be handed over to the City in a GIS database which can be used to update the inventory for the future development. In addition, the dataset obtained from all models will also be stored in a separate GIS database for future use. This will be useful to develop a comprehensive database to exchange adequate and common information regarding hydrology, flood plain restoration, water quality to inter-agency, or among different municipalities within two study watersheds.

2.3. Engineering Leadership Plan: SIUC's Communications and Marketing office shares SIUC's story with its most important constituents, are strategic partners, helping offices across campus achieve their goals within the larger framework of the university's mission and brand. Communication's office help the university achieve its goals using communications and marketing strategies that engage audiences and represent best professional practices. The office will recommend comprehensive strategies designed to help achieve goals and make the most efficient use of available resources. In relation to the proposed project, SIUC's communications office will work closely with the PI's in assistance with the PM to communicate the project goals and outcomes to the relevant stakeholders. This would include writing news releases at appropriate key times before, during and after the researchers complete their work. Also, the office will promote public events as needed and cooperate with communication department of municipal partner's as needed to ensure the public is aware and educated on the project. Some of the activities and events during the planning phase will be under the supervision of the PM including **open house meetings** (all municipalities will conduct multiple open houses to discuss the benefits of the proposed project and taking into account the restriction posed by flood events and climate extremes, these open houses may need to be held virtually due to COVID-19), **social networking event** (as permitted by local authorities due to COVID-19 after the completion of a milestone as set by PM), **special events** (information about the project will be available at all special events hosted by the city), **city's website** (information about the project will be kept on a dedicated website for community feedback), **social media** (planning process and open-house related information, research updates and project pictures will be posted on Facebook, Twitter, Instagram, and **Nextdoor** - a social networking service for neighborhoods), and the **city newsletter, and University's webpage**. A detailed schematic of the communication plan is shown in Figure 7.

<u>The proposed research will focus on developing a strong framework for better preparing communities during natural disasters in collaboration with multiple agencies such as MSD, 21 municipalities in Deer Creek Watershed and 3 in East St. Louis, Deer Creek Watershed Alliance, Green River Habitat Alliance, Missouri Department of Transportation, East-West Gateway Councils of Government, Community Builders of Network of Metro St. Louis, USACE, IL EPA Region 5 and SIUC & SIUE scholars</u>. PM-Gruenenfelder will be working with all stakeholders for accomplishing the required project goals, coordinating the project and assisting in preparing the deliverables. The integrated decision support system from intra-municipality coordination will help the agencies to recognize the needs and have a shared vision is the utmost goal in this project. The proposed improvements will revitalize a struggling community corridor. The aim of revitalization will be carried out by reducing flooding events and improving water quality by GI's and in-stream restoration efforts. The greenway and flood mitigation will be addressed, the proposed research activity will involve the synergistic integration of engineering technologies with the goal to improve the social, economic, and environmental well-being. As a part of the project initiation, various City Managers along with their respective Communication Managers and project partners will present at the public Board of Alderman meetings and open houses and will address community members' questions, comments, and concerns. **Residents of both the study areas will be**

Fig 7. Communication Plan

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extensively involved in all stages of project planning beginning with initial stakeholder and public meetings. This research proposes an extensive community collaboration with the aim to co-design and co-create the engineering technology with the direct help of the community. To support a community engaged strategic plan, we propose to create an advisory council that will include residents, community leaders, government officials, project planners, and university researchers. The tasks of the council include meeting to discuss general barriers, challenges and available resources for the study area and identifying goals, aims, and resources designated for implementation and co-evaluation of the strategic plan.

2.4. Evaluation Plan: The goals associated with this research task are well planned and meticulously defined to judge the success of the project in terms of its applicability and implementation. The following goals are defined to serve the purpose of measuring the success of the research work.

2.4.1 Efficient operation & maintenance (O&M): The research will provide a basis to handle the operations and maintenance plans for both the study watersheds to offer continual flood protection benefits, continued recreational opportunities, and ecosystem maintenance for the community and to ensure the long-term success of the project. The general recommendations based on the relevant outcomes of the research with regards to the future infrastructure and as well as the climate change impacts will be to inspect and when necessary, remove debris, reinforce stream bank protection and outlet control stability on an annual basis, or after heavy rain events. The management will administer regular landscape maintenance, which will include continual invasive species management. It will also include, weeding, mulching, dead leaves removals, checking pH/soil fertility if plants show signs of nutrient deficiency, fertilization, and watering. The timing will vary as weekly, monthly, or annually. The City Managers will take over the O&M responsibility after the completion of the proposed research.

2.4.2 Flood reduction and improving water quality: The installation of the GI's and in-stream restoration features in the selected watersheds will be key to monitoring the progress of the flood mitigation work and water quality improvement. In particular, the research team will carry out the extensive hydrologic and hydraulic and water quality modeling that will show the expected positive changes in the 100-year floodplain as a result of the proposed improvements and identified historic peak flood levels for multiple large, damaging storm events. Monitoring of flood events in the project area during high intensity storms (and comparing against similar modeled historic flood levels for similar peak flow rates) will be a critical component of determining the project's progress in improving water quality and ecosystem services. Multiple BMPs throughout watersheds will be analyzed and monitored to understand any spatial extents of hydrological and hydraulic benefits. Effectiveness of the sustainable flood control practices is measurable by flow rate and flood depth comparisons, improvement in water quality, reductions in nuisance flow, reduction in flood response related staff hours and city expenses for flood events, and necessary rescue efforts (currently, boat rescues are a regular occurrence during severe flood events).

2.5 Scope and Scale: We propose an interdisciplinary approach to increase community resilience by reducing flooding events, improving water quality, and restoring the ecosystem through the use of available technological advances with the partnering effort among scientists, professionals, and stakeholders. With this project the PIs intend to i) mitigate flooding issues and improve water quality within the community resilience in chronically hit areas, ii) restore the floodplain and local ecosystem services, iii) evaluate future flooding events under changing climate, and (iv) understand the impact of proposed improvements on a community's natural and social capitals. The project will also involve a sustainable approach of best management practices to enhance the hydrologic efficiency of the study region along with the improvement of ecosystem services (e.g. healthy river systems and riparian buffer zones). We provide several ways to increase awareness among residents, stakeholders and practitioners about the state-of-the-art technologies involved for tracking and mitigating the flooding events. In addition, residents will be included throughout the process as they will be the direct beneficiaries of the project. ***The proposed project will directly benefit the residents within the study area, Deer Creek in Missouri and East St. Louis in Illinois. Additionally, the project will benefit 2 million people in the 1,200 square mile Great Rivers Greenway service district in St. Louis City, St Louis County and St. Charles County in Missouri.*** A major aspect of the project is community engagement with community stakeholders occupying an integral position in the research. Investigators and community stakeholders will work closely to develop, and evaluate creative approaches to accomplish the goals of the proposed research with the primary intent of benefiting both study watershed and the surrounding Greater St. Louis community. Through this project, we will introduce new ways to incorporate communication technologies, state-of-the-art water resources science and ecological knowledge with the main intent to engage interdisciplinary representatives through education, research and implementation opportunities. In addition, interdisciplinary courses will be developed to motivate future professionals to promote sustainable and safe practices for flood and ecosystem management. Moreover, professionals will be recruited to participate in workshops and seminars aimed at developing new insights and strategies to minimize the flood hazard, improving water quality, and enhance ecosystem services. The coordination required among multiple agencies for installation and monitoring of the BMPs and in-stream restoration features is required for solving complex Engineering Problems that will help to develop a comprehensive plan to manage, promote and execute the urban sustainability resilience plan.

2.6 Broader Impacts: The proposed project is multidimensional in scope and unique in how it fits into the comprehensive vision of LEAP HI program. Specified objectives, which can be thought of as benefits to the engineering community, have direct hydrological, environmental, ecological, technological, social and economic impacts that extend far past the traditional benefits of improving water quality and quantity. Quantifying the merits of these nature-based solutions requires analyzing project outcomes with a holistic lens. Ecological services will be improved through the removal of pollution and contaminants in the air, water and soil, and by the expansion of natural habitat for endemic flora and fauna. Socioeconomic services will be improved through averted damage costs and increased property values. Flood mitigation and water quality research in this area has large safety benefits, with a significant reduction in personal rescues, property damages, and state highway closures and improvements in quality of life.

Engineering and Public Health Research: The project will mitigate chronic flooding and improve water quality along Deer Creek Watershed in Missouri and Centerville in Cahokia Canal/Horseshoe Lake Watershed. The project will achieve this through reducing impervious surface area, monitoring and modeling water quality, and floodplain restoration. Floodplain habitat and the main channel of the creek will be revegetated and restored, and the streambanks will be widened to more stably and safely convey floodwaters. The proposed project will address stream restoration and bank stabilization through debris removal, landscaping, erosion and sediment control, and monitoring equipment. The proposed research makes fundamental advances in multiple areas from computer vision, deep learning, and ML, as well as water and fish habitat quality. The successful completion of this project will facilitate flood relief, habitat restoration, community well-being through reduced flooding events and improved water quality and public health. The outcome of the proposed study will have impacts on future watershed management policies providing crucial information about interaction between watershed hydrology, water quality and riverine ecosystem. Furthermore, it will be beneficial to analyze the impact of future climate change on water quantity and quality and tragedy to offset the impacts for sustainable watershed management. This study results will be specifically crucial for Midwestern river systems, which is impacted by degraded water quality (e.g., excessive nutrient, low DO and high suspended sediment concentrations). The study will provide a tool to quantify the impacts of changes in water quantity and quality due to current resources management (e.g., agricultural practices). Further, the outputs from the models, more specifically the project outputs will be handed over to City Managers for open access public use in the form of GIS database. These objectives will be achieved through increased coordination between scientists, professionals, community members and students. The proposed research is designed to involve students of different levels (K-12, undergraduate and graduate). Under the PI's guidance, students will improve their skills for interdisciplinary research in the future. PIs will also improve existing education and research activities whilst increasing the participation of underrepresented students. Apart from research, graduate and undergraduate students of SIUC and SIUE will also assist in community engagement and engineering tasks to achieve professional experiences through summer internships.

Social Sciences Research: To measure the impact of the project on residents of both study areas, as well as to incorporate their input during the design and implementation phases, quantitative and qualitative data will be collected on community residents at several points in time during the project.

Survey residents within the study area: At the beginning of the project, we will randomly sample 1000 households from each study area requesting that the adult with the next birthday fill out the survey. To ensure a high response rate, we will make up to five contacts with each household in the sample, provide them with an option to fill out the survey by hand and mail it with a postage-paid envelope or complete the survey online. PM-Gruenenfelder will overlook the surveys with the assistance from the local City Managers. We will survey residents again at the midpoint of the study (year 3) and at the end (year 5). Undergraduate students will assist in the process of survey data collection. The questions will address residents' levels of community sentiment, indicators of social capital, and perceptions of the study area, including what they would like to see as the outcome, their perceptions of the process and their perceptions of the final outcome. An example survey question measuring community sentiment is a matrix style question with the lead in: ***Please rate your community as a place to live by indicating whether you agree or disagree with the following statements:*** *1) Being a resident is like living with a group of close friends. 2) If you do not look out for yourself, no one else area will. 3) Most everyone is allowed to contribute to local governmental affairs if they want to. 4) When something needs to get done, the whole community usually gets behind it. 5) Community clubs and organizations are interested in what is best for all residents.* Policy-relevant survey research will be conducted. During the survey collection process, age, gender, race, and partisanship will also be reflected in a region's demographics. Any imbalances in the survey sample will be quickly detected and corrected in the field, rather than relying solely on post-survey techniques for big corrections. Social science coupling with engineering smart solutions is essential to address racial inequity and urbanization issues contributing to deteriorate water infrastructures and quality that facilitates the communication with the residents to maintain water quality and infrastructures in an efficient way.
Conduct focus groups discussions within the study area: One of the questions in the survey will be if the respondent would like to participate in a focus group to better understand barriers and challenges they see in the community and what goals they would like to see for the study area. We will then hold two to three focus groups comprised of volunteer residents, with a maximum of 20 residents in each focus group. We will take measures to ensure that each focus group is diverse concerning age, gender, and race and ethnicity. During the focus groups, a facilitator will ask residents open-ended questions about the community and study area, with an emphasis on discussing some of the design plans for the study area.

3. Educational Component

3.1. Background: PIs plan to mentor and support students of all backgrounds to pursue advanced degrees and to contribute to research projects in the fields of water resources, climate, sustainability, environmental resources and management. PIs will engage in uplifting existing education and research activities whilst increasing the participation of underrepresented students. PIs are passionate in improving educational outcomes for traditionally underrepresented groups. For example, PI- Kalra have developed programs like **STEAM** summer camps for girls, **Saluki Day**, and **Saluki Water Workshops** (Figure 8), which encourages young students to explore careers in STEAM disciplines. PI-Crowe is involved in an NSF S-STEM grant that provides annual stipends for students to be involved in a three-year scholar program. When selecting students for the program, emphasis was placed on selecting female and racial minority applicants. Also, the technical aspects of the project will be presented at appropriate ACM, IEEE, hydrology, hydraulic, and ML community conferences. The PIs will hold tutorials on the technology at conferences.

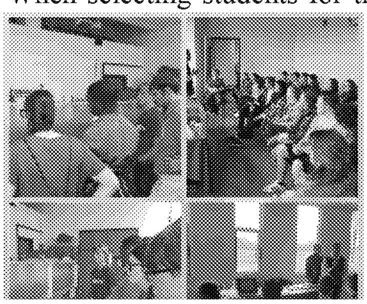
Fig 8. STEAM program presentations at SIUC

3.2. Student involvement: High school students will be taught about human impacts, flooding hazard, and ecosystem balance. Activities will include a one-day field visit and a monthly one-hour class during the course of a semester. High school students will learn the role of STEAM disciplines in flood hazard management and ecosystem restoration, along with the social benefits. Likewise, undergraduate students will be involved during the summer to assist with data collection with respect to the research questions. Undergraduate students will be selected on a competitive basis for a summer field trip to analyze the cottonwood recruitment and to prepare GIS based vegetation maps. Apart from research, graduate and undergraduate students of SIU will also assist in community engagement and engineering tasks to achieve professional experiences.

3.3. Development of new course modules: In order to expand the knowledge and scope of the interdisciplinary education, PI-Kalra will design a course entitled **Urban Runoff Quality & Control** and will cover topics of water and environmental facilities, water economy analysis, and optimization algorithm. PI-Kalra has developed a new junior level **Introduction to Sustainability** course, which has been taught since fall 2018. PI-Fakhraei will develop an advanced undergraduate course entitled **Aquatic Chemistry**. In this class, students will learn aquatic chemical systems through thermodynamic chemical equilibrium calculations. PI-Benjankar will develop a senior level course in **Aquatic Ecosystem Management**. The course will focus on restoring aquatic and riparian habitats. PI-Crowe regularly teaches courses on **Environment and Society and Community Development**. Undergraduates in these courses during the time of data collection will assist in the focus groups. Research findings will be included as case studies on topics of community sentiment, natural capital, social capital, and community engagement. Students will also attend virtual meetings with stakeholders. PI-Rekabdar will design a course entitled **Machine Learning for Environmental and Water Resource Systems**. She will cover topics of artificial intelligence methods for data analytics in the area of water and flood management systems.

The educational goal of this study is to raise awareness about the interaction between watershed hydrology, ecosystems (aquatic and riparian) and to show engineering students about their roles not only in designing infrastructures, but also their impacts on natural hydrologic and ecosystems. They will also learn about importance of protecting, maintaining and restoring the ecosystems via sustainable engineering technology and practice. The project has the following educational objectives:(1)To attract young high school students into ecosystem and future management careers (2)To involve undergraduate and graduate students from a underrepresented groups in an integrated hydrological, ecosystem and societal benefit research project;(3) To communicate study results to local community, stakeholders and water and ecosystem managers.

3.4 Expected outcomes of educational component:

1. Inclusion of racial, ethnic minorities and female students to community outreach and research activities.
2. Broad and diversified training on components of water supply and demand, sustainable water management, water and environmental resources, geography, climate, land use and provide knowledge about several water resources software.
3. Encouragement of undergraduates in research and motivate them to further their knowledge boundary.
4. Broad exposure of high school students to research, thus motivating them to pursue STEAM disciplines.

4. Prior NSF Support: **PI-Crowe:** Award S-STEM 1564954 $3,271,703; Period: 08-2016 – 07/2021; Title: Collaborative Research: Upper Delta Region Biodiversity Scholarship. Summary of Results: Intellectual Merit: The overall objective is to recruit, retain, and train students, particularly students from traditionally underrepresented groups, in specimen collections so that they graduate and are ready for graduate school or the workplace. While the scholarship program is only in its second year, preliminary results show that scholarship participants participate in more scholarly activities, interact more with their professors, and are more engaged in the profession than a similar group of non-scholars in the major. Broader Impacts: Publications: Students have presented their own work at conferences and to each other at annual summer institutes. Crowe presented early results at the 2018 Rural Sociological Society. Publications are forthcoming. **PI-Rekabdar:** Award 1951741; Period: 06-2020 -11/2022; Title: Enhancing High-resolution Terrain Data Model for Improving the Delineation of Multi-scale Hydrological Connectivity. Intellectual Merit: The project is to establish a novel geospatial and hydrological modeling approach for improving the delineation of hydrologic connectivity using high-resolution digital elevation models (HRDEMs). Accurate topological network of hydrologic features is critical to manage a wide range of environmental issues, such as nonpoint source nutrient transport and aquatic species passage. This research will improve the characterization of hydrologic features and their connectivity at multiple scales by designing a geospatial artificial intelligence-hydrological modeling framework. Broader Impacts: Graduate students are working on this project to design novel methods and improve the preliminary results. Publications are forthcoming.